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Radionuclide Concentrations in Predator and Bottom-Feeding Fish Upstream and Downstream of Los Alamos National Laboratory: 1976 to 2002

(With Special Reference to the La Mesa and Cerro Grande Fires)

Los Alamos
NATIONAL LABORATORY

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Front Cover: Crew members collecting fish samples on the Rio Grande with an electrofishing unit.

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by

P.R. Fresquez, L. Soholt, K. Bennett, and G.J. Gonzales

ABSTRACT

Radionuclide concentrations, trends, and dose assessments were determined in predator (e.g., trout, bass, pike) and bottom-feeding (e.g., catfish, carp, sucker) fish collected from reservoirs upstream (Abiquiu, Heron, and El Vado) and downstream (Cochiti) of Los Alamos National Laboratory (LANL) from 1976 to 2002. Comparisons were also made in fish collected at Cochiti reservoir before and after fires that burned over LANL lands—the La Mesa fire in 1977 and the Cerro Grande fire in 2000. In general, the average levels of ^{3}H, ^{90}Sr, ^{137}Cs, ^{238}Pu, and ^{239}Pu in predator and bottom-feeding fish collected from Cochiti reservoir over the past two-and-one-half decades were not significantly different ($\alpha = 0.05$) than fish collected from reservoirs upstream of the Laboratory. Total uranium was the only element that was found to be in significantly higher concentrations in both predator and bottom-feeding fish from Cochiti as compared to fish from upstream reservoirs. The higher uranium concentrations in fish collected from Cochiti, however, were related to natural sources. Although the long-term means were not significantly different from background fish, trend analyses show that ^{3}H and ^{239}Pu in fish from Cochiti were significantly increasing over time, whereas ^{90}Sr and ^{137}Cs in fish from Cochiti were significantly decreasing over time. The "worst case" net committed effective dose equivalent from the ingestion of the maximum amount of fish per year (46 lb) using the upper bound (mean plus two standard deviation) concentrations of seven radionuclides in fish from Cochiti was only 0.07% of the International Commission on Radiological Protection all pathway public dose limit. Also, there were no statistical differences in radionuclide concentrations in fish collected from Cochiti after either of the fires that burned on LANL lands in 1977 and 2000 as compared to fish collected before the fires.

I. INTRODUCTION

The source of most radioactive elements detected in the environment is from fallout produced by nuclear weapons testing (Klement 1965), the burn-up of satellite power sources in the atmosphere (Perkins and Thomas 1980), and common minerals in the earth's crust (Whicker and Schultz 1982). Other sources include planned or unplanned releases of radioactive contaminated gases, solids and/or effluents from nuclear weapons research, and development and testing facilities (USDOE 1979). Treated and untreated radioactive liquid waste effluents, for example, were discharged by Los Alamos National Laboratory (LANL) into several dry canyon bottoms in the early years of operations (Purtymun 1975, Gallaher et al. 1999). There are 19 canyons that traverse through LANL property, and, although most of the runoff and/or effluent flow in the canyons is lost to the underlying alluvium and to evapotranspiration before leaving LANL lands (Stephens et al. 1993), some flow resulting from excessive storm events may eventually reach the Rio Grande (Abeele et al. 1981, Gallaher et al. 1999).

Fish constitute one pathway (ingestion) by which radionuclides can be transferred to humans (Nelson and Whicker 1969, Gustafson 1969). As part of the environmental surveillance program at LANL, fish have been collected since 1976 from Cochiti reservoir, a 10,690-acre flood and sediment control project located on the Rio Grande approximately five miles downstream from the Laboratory (Fresquez et al. 1994, Booher et al. 1998, Fresquez et al. 1999). Radionuclides in fish collected from Cochiti reservoir are compared to fish collected from Abiquiu, Heron, and El Vado reservoirs. Abiquiu, Heron, and El Vado are located on the Rio Chama, upstream from the confluence of the Rio Grande and intermittent streams that cross Laboratory lands. These reservoirs are also sufficiently distant from the Laboratory as to be unaffected by airborne emissions.

This report summarizes radionuclide concentrations in predator and bottom-feeding fish from 1976 to 2002 and expands the database by 13 years (Fresquez et al. 1994). Also, comparisons were made in fish collected from Cochiti reservoir before and after two catastrophic fires that burned over LANL lands—the La Mesa fire in 1977 that burned approximately 2,530 acres (Foxx 1984, Lissoway 1996) and the Cerro Grande fire in 2000 that burned approximately 7,500 acres (LANL 2000). As a result of fire, radionuclides that have accumulated in soils, vegetation, and duff from worldwide fallout may be mobilized (Fresquez et al. 2000, Fresquez et al. 2001a, Gonzales et al. 2001, Gonzales and Fresquez 2002, Kraig et al. 2002), and there are areas within the Laboratory that contain radionuclides in soils and plants above background (fallout) concentrations (Fresquez et al. 1998, Gonzales et al. 2000). Results of sampling have shown that the after effects of the Cerro Grande fire, for example, had increased concentrations of radionuclides in runoff down LANL canyons (Johansen et al. 2001, Gallaher et al. 2002). However, these fire-related constituents were mostly bound to suspended sediments in the runoff (i.e., not dissolved in water) and deposited on LANL lands. While the median concentrations of radionuclides in runoff collected from the most downstream LANL boundary were approximately the same as in previous years, the total mass/flux of many radionuclides carried by the runoff increased by about one order of magnitude (Gallaher et al. 2002).

II. METHODS

Samples of fish were collected from Abiquiu, Heron, and/or El Vado reservoirs, located upstream of LANL, and Cochiti, a reservoir located downstream of LANL (Figure 1). Fish were collected using gill nets, trotlines, and rod and reel from 1976 to 2002 between the months of May and September.

Fish were separated into two categories for analysis: predator and bottom-feeding fish. Predator fish collected over the years consisted of rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), kokanee salmon (*Oncorhynchus nerka*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieui*), white crappie (*Pomoxis annularis*), and walleye (*Stizostedion vitreum*). Bottom-feeding fish collected over the years included the white sucker (*Catostomus commersoni*), channel catfish (*Ictalurus punctatus*), carp (*Cyprinus carpio*), and carp sucker (*Carpiodes carpio*). The latter fish derive most of their food supply from the bottom portion of the reservoir(s) and would be more likely to ingest any contamination present in sediments than the surface-feeders (predator fish) (Gallegos et al. 1971).

At the laboratory, the fish samples were processed by separating the muscle and associated skeleton from the viscera (entrails). The muscle plus bone samples were rinsed thoroughly with distilled water and towel dried. About 1,000 g of the fish muscle (and associated skeleton) were placed into tared 1-L beakers and weighed. The beaker contents were oven dried at 80ºC for 120 h, weighed, and ashed at 500ºC for 120 h. The sample ash was weighed, pulverized, and homogenized before it was submitted to an analytical laboratory for the analysis of ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239,240}Pu, and total uranium (U).

Analysis for most years (1976–2000) was conducted by LANL, and the latter years' (2000–present) analysis was conducted by Paragon Analytics, Inc., located in Fort Collins, Colorado. All methods of radiochemical analysis have been described previously (Salazar 1984, Fresquez et al. 1994). Results are reported on an oven-dry-weight basis (dry g). For the analysis of ^{3}H, a small subsample (~100 wet g) was placed into a 1-L beaker and heated to collect distillate (water). Results are reported on an activity per mL basis. The ratio of ^{235}U to ^{238}U was determined by thermal ionization mass spectrometry (Efurd et al. 1993) on samples of fish ash collected and processed during the 1993 season.

Variations in the mean radionuclide content between upstream and downstream predator and bottom-feeding fish samples were tested using a Student's t-test on normal or log-transformed data at the 0.05 probability level. All of the data collected were graphed and subjected to a nonparametric Mann-Kendall test for trends at the 0.05 probability level (Gilbert 1987).

The committed effective dose equivalent (CEDE) was calculated following procedures recommended by the Department of Energy (USDOE 1991) and the Nuclear Regulatory Commission (NRC 1977). The general process for calculating radiological dose from ingestion of fish was as follows. First, after converting from dry to wet weight concentrations (Fresquez and Ferenbaugh 1998), the wet concentration of radionuclides in the meat was multiplied by a dose conversion factor that relates radiological dose to activity concentration per unit mass of food ingested (USDOE 1988). Where different dose conversion factors are provided for a radionuclide, the most conservative (highest) factor was used. The final dose was calculated by multiplying the dose per unit mass ingested by the total number of units ingested per year. The dose calculated is the 50-year CEDE. Even though this dose would be received over a 50-year period, the entire dose was reported as though it occurred in the year the fish were ingested. Three calculations were performed: dose per lb of fish consumed, dose per average consumption rate (12.5 lb of fish per year), and dose per maximum consumption rate (46.2 lb of fish per year). The dose per lb of fish consumed was reported so that individuals may calculate their own doses based on their knowledge of their actual consumption rates.

III. RESULTS AND DISCUSSION

a. Radionuclide Concentrations

All of the (radionuclide) data collected for predator and bottom-feeding fish upstream and downstream of the Laboratory between 1979 to 2002 and 1976 to 2002 can be found in Appendix A and Appendix B, respectively. The means of these radionuclides for each fish type can be found in Table 1. Most radionuclides, with the exception of uranium, were not significantly different in predator and bottom-feeding fish collected from Cochiti reservoir as compared to fish collected upstream of the Laboratory. These results are identical to results reported in an earlier assessment (Fresquez et al. 1994, Fresquez and Armstrong 1996) and are similar, particularly Sr and Cs, with crappie, trout, and salmon collected from (background) reservoirs and lakes in Colorado (Whicker et al. 1972, Nelson and Whicker 1969).

Total U was the only element that was significantly higher in predator and bottom-feeding fish collected from Cochiti as compared to background levels. The differences between the mean values, however, were small, and the isotopic ratio of ^{235}U (1.25×10^{13} atoms/g ash) to ^{238}U (1.74×10^{15} atoms/g ash) in Cochiti bottom-feeding fish collected during the 1993 season were consistent with naturally occurring uranium (e.g., 0.0072) (Efurd 1994). Also, recent studies of sediment samples collected within the Rio Grande (Gallaher and Efurd 2002) and Cochiti reservoir (Gallaher et al. 1999) show the uranium to be from natural sources. In other words, there was no evidence of depleted uranium in these fish or sediment samples. Depleted uranium, a by-product of uranium enrichment processes, has been used in dynamic weapons testing at Laboratory firing sites since the mid-1940s (Becker 1992). Instead, the higher uranium concentrations in fish samples from Cochiti as compared to fish collected upstream of LANL were probably a result of the following: (1) Cochiti receives greater amounts of sediments than the other reservoirs. (2) There are more uranium-bearing minerals around the Cochiti area. Uranium in Bandelier tuff around the Los Alamos area is higher (4.0 to 11.4 $\mu g\ g^{-1}$) (Crowe et al. 1978, Fresquez et al. 1998) than in soils from areas upstream of Cochiti (1.3 to 3.9 $\mu g\ g^{-1}$) (Purtymun et al. 1987, Fresquez et al. 1998). And, (3) Some uranium may be entering Cochiti reservoir via the Santa Fe River as this river flows past the edge of an abandoned 25-acre uranium mine site (La Bajada Uranium Mine) approximately 9.7 km (6 mi) upstream and northeast of Cochiti reservoir.

As expected, the bottom feeders from both downstream and upstream reservoirs contained higher average uranium contents (12 ng/dry g) than the surface feeders (4 ng/dry g). The higher concentration of uranium in bottom feeders as compared to surface feeders may be attributed to the ingestion of sediments on the bottom of the lake (Gallegos et al. 1971). Sediments represent the accumulation or sink compartment for most radionuclides in reservoirs (Whicker and Schultz 1982).

b. Committed Effective Dose Equivalent

Based on the mean concentrations of these radionuclides, the CEDEs from the consumption of various amounts of fish from upstream and downstream reservoirs were very low and very similar to one another (Table 2). In fact, CEDEs, based on mean concentrations from fish ingested from Cochiti reservoir were lower than from upstream sources. The "worst case" (the mean plus two standard deviations in fish from Cochiti at the maximum ingestion rate) net CEDE (0.065 mrem/y) was less than 0.07% of the International Commission on Radiological Protection public dose limit for all pathways of 100 mrem/y (ICRP 1978).

Over 85% of the dose was a result of ^{90}Sr in the muscle plus bone portion of the fish. Strontium-90, an analog of Ca, deposits primarily in the bone (Whicker and Schultz 1982); and, therefore, the "worst case" dose to people that consume only the edible portions of the fish (muscle only) would probably be significantly lower (i.e., about 85% lower or around 0.0098 mrem/y).

c. Trend Analysis

Trend analysis shows that ^{3}H in predator fish and ^{239}Pu in bottom-feeding fish from Cochiti have significantly increased over time (Table 3). Although these radionuclides in fish from Cochiti were not statistically different from fish collected upstream of LANL, ^{3}H has been routinely detected in other biota around LANL (Fresquez and Gonzales 2000), and ^{239}Pu has been detected in deep core sediments at Cochiti (Gallaher et al. 1999). Plutonium-239, however, is not assimilated very readily by biota (Whicker and Schultz 1982) and the reason for the increase is not completely known. In contrast, ^{90}Sr and ^{137}Cs in both predator and bottom-feeding fish upstream and downstream of LANL show significant decreases over time. Since ^{90}Sr and ^{137}Cs have about a 30-year half-life, these results may reflect the decay of these particular radionuclides over time.

d. Effects of Fires

The results of the analysis of radionuclide concentrations in fish after two major fires that burned within LANL lands can be found in Table 4. In general, all radionuclide concentrations in fish collected one month to two years after the fires, particularly the Cerro Grande fire which swept over 7,500 acres of LANL lands, were not significantly different from radionuclides in fish collected before the fires occurred. These data are in general agreement with the quality of runoff after the Cerro Grande fire (Johansen et al. 2001, Gallaher et al. 2002), but are in stark contrast to the modeled (upper bound) estimates made by Risk Assessment Corporation (RAC) (RAC 2002). RAC was employed by the New Mexico Environment Department to estimate the risk to the public from chemicals and radioactive materials released to storm water from source areas in the LANL environs after the Cerro Grande fire. They reported that of the different exposure possibilities evaluated the largest potential for exposure was from eating fish from the Rio Grande or Cochiti reservoir as a result of ^{137}Cs, mercury, polyaromatic hydrocarbons, and high explosive materials. With respect to ^{137}Cs, calculated concentrations in fish equivalent to the risks predicted by RAC were on the order of three to four orders of magnitude higher than values measured after the fire.

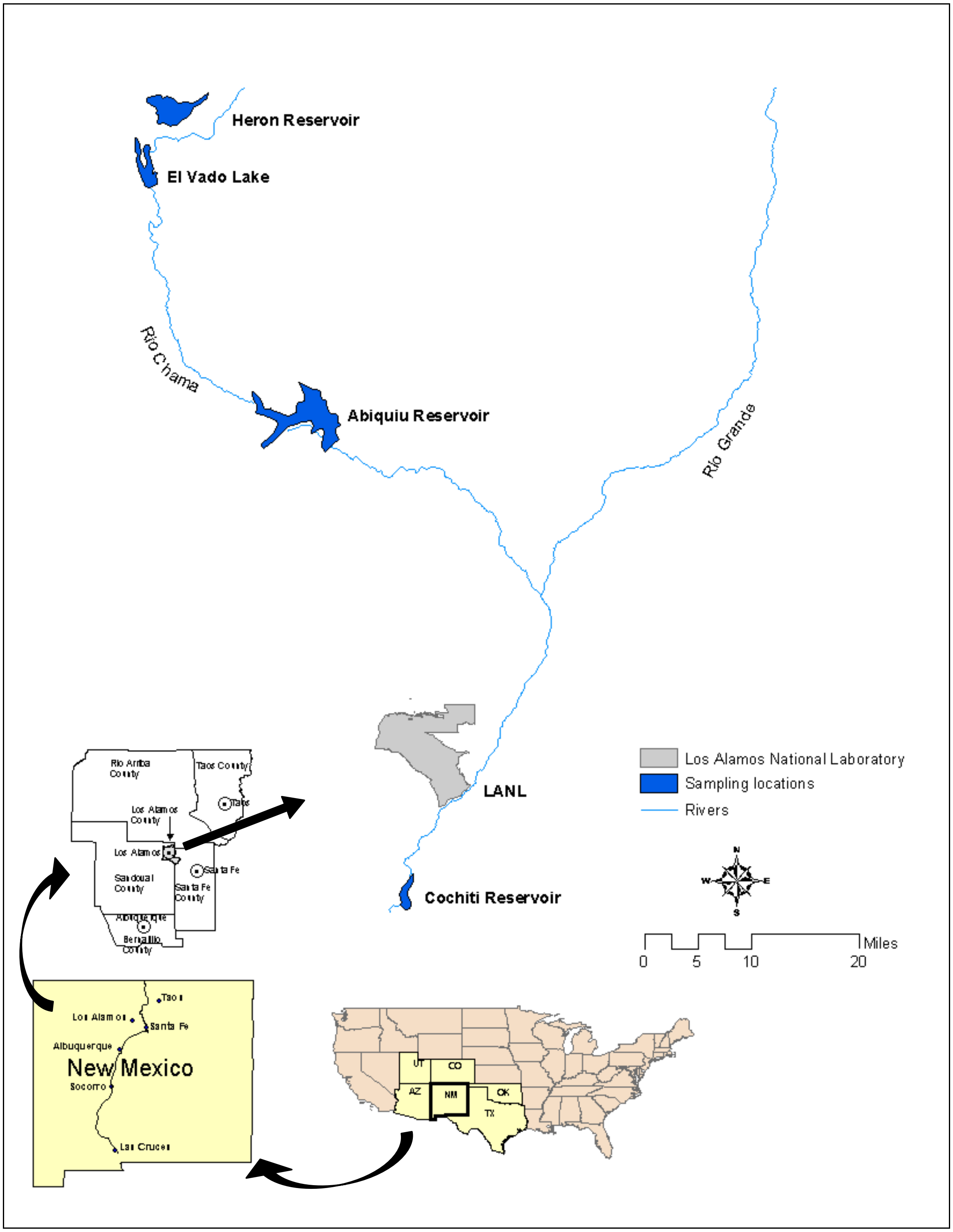

Figure 1. Fish Sampling Locations in Relation to Los Alamos National Laboratory.

Table 1. Mean (±SD) Radionuclide Concentrations in Predator and Bottom-Feeding Fish Upstream and Downstream of Los Alamos National Laboratory from 1976 to 2002.

Fish Type/ Location	^{3}H pCi/mL	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	$^{239,240}Pu$ (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
Predator Fish							
Upstream	0.0 (0.3)	4.2 (4.7)	6.7 (13.8)	2.8 (1.6)	-0.5 (10.4)	7.7 (10.2)	13.7 (20.7)
Downstream	0.2 (0.3)	5.1 (3.0)	2.4 (6.1)	5.0 (2.2)*[a]	4.5 (12.3)	6.1 (7.4)	29.2 (55.0)
Bottom-Feeding Fish							
Upstream	-0.0 (0.2)	5.2 (3.8)	6.6 (11.1)	8.1 (4.1)	3.8 (7.8)	4.5 (6.9)	10.3 (9.3)
Downstream	0.3 (0.5)	4.0 (2.4)	-0.4 (28.1)	15.3 (11.6)*	3.3 (12.2)	3.1 (6.6)	19.0 (25.0)

[a]Means within the same column and fish type followed with an * were significantly different at the 0.05 probability level using a Student's t-test on normal or log-transformed data.

Table 2. The Committed Effective Dose Equivalent for the Ingestion of Fish Collected Upstream and Downstream of LANL.

Fish Type/ Location	mrem/lb (±2SD)	Average[1] mrem/y (±2SD)	Maximum[2] mrem/y (±2SD)
Predator			
Upstream	0.0027 (0.0022)	0.034 (0.028)	0.125 (0.102)
Downstream	0.0012 (0.0013)	0.015 (0.016)	0.055 (0.060)
Bottom-Feeding Fish			
Upstream	0.0016 (0.0020)	0.020 (0.025)	0.074 (0.092)
Downstream	0.0012 (0.0038)	0.015 (0.048)	0.055 (0.176)

[1]Average consumption rate for muscle plus bone is 12.5 lb (5.7 kg) per person per year.
[2]Maximum consumption rate for muscle plus bone is 46.2 lb (21 kg) per person per year.

Table 3. Results of the Kendall Tau Test for Trend in Predator and Bottom-Feeding Fish Upstream and Downstream of Los Alamos National Laboratory during the Period 1976 through 2002.

Fish Type/ Location	^{3}H pCi/mL	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	^{239,240}Pu (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
Predator Fish							
Upstream	0.45 D[a]	0.05 D*	0.02 D*	0.96 NT	0.35 U	0.05 U*	0.88 NT
Downstream	0.04 U*	0.00 D**	0.50 D	0.23 U	0.52 NT	0.34 U	0.83 NT
Bottom-Feeding Fish							
Upstream	0.60 D	0.00 D**	0.02 D*	0.03 U*	0.01 U**	0.17 U	0.88 NT
Downstream	0.17 U	0.01 D**	0.00 D**	0.12 U	0.94 NT	0.01 U**	0.94 NT

[a]D = downward trend, U = upward trend, and NT = no trend

[b]* and ** denote significance at the 0.05 and the 0.01 probability level, respectively.

Table 4. Mean (±SD) Radionuclide Concentrations in Fish Collected at Cochiti Reservoir Before (B) and After (A) the La Mesa, Dome and Cerro Grande Fires.

Fire/Fish Type/Years (Time after Fire)	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	^{239,240}Pu (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
LA MESA (1977)						
Bottom-Feeding Fish						
B1976[a]	[b]	-0.8 (4.9)	2.0 (2.1)	-6.4 (6.7)	-4.4 (0.3)	
A1979 (2y)[c]	9.2 (5.5)		10.3 (5.7)	-13.0 (17.3)	-11.4 (13.0)	
CERRO GRANDE (2000)						
Predator Fish						
B1997–1999[d]	2.6 (2.8)	1.6 (1.3)	3.5 (2.1)	3.0 (19.2)	13.4 (18.8)	97.0 (140.8)[e]
A2000 (1m–3m)[f]	1.7 (3.0)	0.1 (1.0)	5.3 (2.2)	7.7 (35.5)	0.5 (13.7)	-11.7 (13.6)
A2001 (10m–1.1y)[g]	2.3 (0.1)	0.5 (1.7)	5.1 (1.2)	14.2 (19.7)	13.6 (4.5)	21.2 (10.1)
A2002 (2y)[h]	2.4 (1.0)	-0.5 (4.4)	9.9 (12.7)	3.8 (21.9)	7.3 (12.5)	35.5 (15.1)
Bottom-Feeding Fish						
B1997–1999[d]	4.7 (4.8)	0.7 (1.0)	20.1 (13.0)	1.6 (12.9)	13.3 (16.4)	31.7 (48.5)[i]
A2000 (1m–3m)[f]	1.2 (3.8)	-0.3 (0.6)	10.7 (6.9)	11.7 (50.1)	6.9 (7.3)	-1.9 (26.4)
A2001 (10m–1.1y)[g]	2.4 (0.1)	0.1 (0.3)	13.8 (1.4)	3.7 (14.2)	0.0 (5.1)	21.0 (11.6)
A2002 (2y)[h]	3.0 (1.0)	-0.5 (2.9)	21.5 (16.7)	0.7 (7.5)	7.8 (5.9)	15.0 (5.4)

[a]Data (n = 5) from Environmental Surveillance Group (1979). [b]Columns with no data indicate that the sample was either lost in analysis or not analyzed. [c]Data (n = 7) from ESG (1980). [d]Data (n = 15) from Fresquez (1998), Fresquez (1999), and Fresquez and Gonzales (2000). [e](n = 10). [f]Data (n = 13) from Fresquez et al. (2001) and is the mean (and std dev) of three collection periods; and there were no statistical differences in any of the radionuclide concentrations between the three collection times. [g]Data (n = 17) from Fresquez et al. (2002) and is the mean (and std dev) of three collection periods; and there were no statistical differences in any of the radionuclide concentrations between the three collection times. [h]Data (n = 6) from Fresquez et al. (in preparation). [i](n = 9).

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APPENDIX A
Mean Radionuclide Concentrations in Game (Surface-Feeding) Fish Upstream and Downstream of Los Alamos National Laboratory From 1979 to 2002.

Location/Year	^{3}H pCi/mL	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	^{239,240}Pu (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
Upstream							
1979		3.7		1.9	-10.7	-0.8	
1980			57. 0		-1.8	-0.7	
1981			13.0	7.0	-13.0	40.0	
1982		1.5	17.0	2.7	0.5	3.0	
1983		4.3	3.8	1.8	0.0	2.0	
1984		6.0	34.0	4.6	14.0	2.0	
1985		5.1	-8.0	5.7	-38.0	1.8	
1986		7.6	-3.8	1.7	3.0	6.0	
1987		19.0	6.0	1.4	-3.0	6.0	
1988			7.1	1.4	3.0	8.0	
1989		8.2	-0.4	2.2	6.0	-0.4	
1990		11.6	2.2	1.7	2.0	5.0	
1991		1.0	0.1	3.2	3.0	3.0	
1992		1.1	9.6	1.2	4.5	14.0	
1993		3.2	0.4	3.3	0.0	5.1	
1994		4.4	10.8	0.9	-0.4	-0.4	
1995	-0.0	6.4	1.5	1.5	2.4	0.0	
1996	0.4	2.9	1.0	3.4	1.5	3.6	9.2

Location/Year	^{3}H pCi/mL	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	$^{239,240}Pu$ (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
1997	-0.1	-0.5	1.9	1.8	-0.8	18.2	10.4
1998	-0.3	-2.8	1.5	2.8	-7.7	-1.0	47.2
1999	-0.0	1.6	0.9	2.7	11.2	22.4	22.3
2000		-0.1	-0.6	2.1	15.9	6.8	-22.9
2001		1.7	0.5	5.3	0.5	24.9	15.3
2002		1.4	-0.3	3.2	-4.8	16.7	14.5
Mean of means	0.0	4.2	6.7	2.8	-0.5	7.7	13.7
Std. Dev.	(0.3)	(4.7)	(13.8)	(1.6)	(10.4)	(10.2)	(20.7)
Downstream							
1979		7.8		1.5	-23.0	-6.0	
1980			6.5		11.0	7.6	
1981			-2.4	3.0	1.0	-4.0	
1982		4.6	5.0	6.3	-2.7	10.0	
1983		9.3	-6.3	8.8	-3.0	6.0	
1984		6.7	7.6	10.0	5.3	8.0	
1985		12.0	-7.9	5.5	-4.4	4.2	
1986		5.2	-2.6	1.6	4.0	9.0	
1987		5.3	12.0	2.4	5.0	5.0	
1988			12.0	2.5	2.0	4.0	
1989		8.7	-4.4	3.4	10.0	8.0	
1990		7.6	20.3	4.9	5.0	7.0	
1991		6.6	0.6	4.8	8.0	4.0	

Location/Year	^{3}H pCi/mL	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	^{239,240}Pu (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
1992		4.1	13.2	5.4	3.3	9.0	
1993		9.2	-0.6	5.5	5.0	4.6	
1994		8.4	3.2	6.6	3.0	0.0	
1995	-0.1	5.4	0.7	3.5	0.0	0.0	
1996 (6/3)	0.1	4.3	1.8	5.0	0.9	9.0	9.5
1996 (8/8)	0.1	3.2	2.1	6.3	2.4	3.8	19.0
1997	0.1	1.7	1.3	3.4	-0.5	5.1	7.0
1998	0.8	2.3	3.0	2.4	-5.1	8.0	187.1
1999	0.2	3.7	0.5	4.6	17.6	30.6	67.9
2000 (6/29)		2.1	-0.4	4.4	-9.2	2.4	-7.5
2000 (7/27)		0.1	-0.1	5.8	2.7	5.6	-13.6
2000 (8/29)		3.7	0.9	6.2	44.4	-11.3	-18.2
2001 (4/25)		2.3	1.9	4.4	5.7	15.4	15.0
2001 (5/30)		2.2	-1.4	6.5	36.8	16.9	15.7
2001 (8/14)		2.4	1.1	4.3	0.2	8.5	32.9
2002		2.4	-0.5	9.9	3.8	7.3	35.5
Mean of means	0.2	5.1	2.4	5.0	4.5	6.1	29.2
SD	(0.3)	(3.0)	(6.1)	(2.2)	(12.3)	(7.4)	(55.0)

APPENDIX B

Mean Radionuclide Concentrations in Non-Game (Bottom-Feeding) Fish Upstream and Downstream of Los Alamos National Laboratory From 1976 to 2002.

Location/Year	^{3}H pCi/mL	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	$^{239,240}Pu$ (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
Upstream							
1976			0.4	1.5	-7.5	-6.0	
1979		13.2		3.4	-10.3	-10.8	
1980			43. 0		-6.3	-0.07	
1981			10.0	6.1	3.7	3.0	
1982		8.1	16.0	10.0	11.0	10.0	
1983		14.0	-7.6	20.0	1.0	3.0	
1984		9.2	19.0	9.7	4.2	3.7	
1985		9.2	0.0	8.2	-0.2	22.0	
1986		5.1	-3.7	6.8	1.0	4.0	
1987		4.2	13.0	5.2	3.0	3.0	
1988			5.4	2.9	3.0	3.0	
1989		3.3	6.2	9.0	0.5	3.0	
1990		4.4	26.8	6.5	5.0	3.0	
1991		2.6	2.1	5.1	1.0	3.0	
1992		3.2	11.0	5.2	4.0	18.0	
1993		4.7	0.8	4.3	7.6	2.9	
1994		4.2	12.2	7.5	2.8	0.0	
1995	-0.0	5.0	1.6	10.3	4.2	0.0	

Location/Year	^{3}H pCi/mL	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	^{239,240}Pu (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
1996	0.1	3.3	0.9	7.4	2.5	3.6	6.3
1997	0.1	2.5	0.8	10.5	12.6	5.5	8.5
1998	-0.3	-2.6	0.3	9.3	5.2	1.2	28.5
1999	0.0	5.2	0.2	10.3	2.5	10.9	14.4
2000		3.8	-0.8	8.3	32.1	12.2	-1.5
2001		2.8	-0.1	15.4	7.4	1.5	7.0
2002		2.8	0.1	12.2	5.9	13.9	8.7
Mean of means	-0.0	5.2	6.6	8.1	3.8	4.5	10.3
SD	(0.2)	(3.8)	(11.1)	(4.1)	(7.8)	(6.9)	(9.3)
Downstream							
1976			-0.8	2.0	-6.4	-4.4	
1979		9.2		10.3	-13.0	-11.4	
1980			38. 0		1.8	-2.2	
1981			5.3	66.0	-0.6	1.0	
1982		7.6	13.0	13.0	6.0	-9.0	
1983		7.6	4.3	27.0	7.0	11.0	
1984		6.4	15.0	27.0	3.1	0.0	
1985		8.0	5.2	19.2	-5.0	8.7	
1986		1.8	-2.2	8.7	1.0	2.0	
1987		5.2	10.0	11.5	5.0	1.0	
1988			7.7	8.2	7.0	4.0	
1989		2.4	-140.0	8.6	1.0	-0.2	

Location/Year	^{3}H pCi/mL	^{90}Sr (10^{-2} pCi/g dry)	^{137}Cs (10^{-2} pCi/g dry)	^{tot}U (ng/g dry)	^{238}Pu (10^{-5} pCi/g dry)	^{239,240}Pu (10^{-5} pCi/g dry)	^{241}Am (10^{-5} pCi/g dry)
1990		1.6	17.8	5.9	3.0	-0.2	
1991		1.7	0.1	9.2	4.0	2.0	
1992		1.5	10.5	8.8	7.6	6.0	
1993		3.5	0.5	12.0	4.2	5.3	
1994		4.9	0.4	20.4	-2.6	0.0	
1995	-0.0	4.2	0.5	8.3	0.8	0.0	
1996 (6/3)	0.4	4.3	1.4	12.1	5.9	10.7	18.1
1996 (8/8)	-0.2	5.2	1.4	11.7	-0.3	2.7	8.9
1997	0.1	5.4	1.2	24.0	0.5	4.8	-5.1
1998	1.1	4.2	0.9	14.0	-9.5	10.0	77.7
1999	0.4	4.6	0.1	21.1	11.4	22.8	30.2
2000 (6/29)		1.3	0.0	15.0	-1.1	9.3	-7.0
2000 (7/27)		1.0	-0.4	6.3	-3.4	6.7	-14.3
2000 (8/29)		1.1	-0.4	10.8	58.3	3.2	41.8
2001 (4/25)		2.5	0.5	15.3	-3.8	1.9	12.4
2001 (5/30)		2.3	-0.1	12.5	20.1	-5.7	34.2
2001 (8/14)		2.5	0.0	13.6	-5.2	3.9	16.4
2002		3.0	-0.5	21.5	0.7	7.8	15.0
Mean of means	0.3	4.0	-0.4	15.3	3.3	3.1	19.0
SD	(0.5)	(2.4)	(28.1)	(11.6)	(12.2)	(6.6)	(25.0)

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